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INTERMEDIATE VISUAL ACUITY OF PRESBYOPIC INDIVIDUALS WITH AND WITHOUT DISTANCE AND BIFOCAL LENS CORRECTIONS

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16. Abstract

Visual acuity was determined at the intermediate range for older individuals with various combinations of ocular refractive error (nine subcategories) and accommodative power (three subcategories). Subjects (N=249) read numerals ranging in size to measure visual acuity from 20/80 to 20/15 at 51, 76, and 102 cm (20, 30, and 40 in) with 50 fL luminance. Monocular visual acuity scores were determined both with the subject's optimum spectacle lens correction for distance vision (6 m, 20 ft) and near vision (0.4 m, 16 in) and without lenses.

For subjects with low accommodative power, neither the distance nor the near lens correction provides normal vision throughout the intermediate range. At 102 cm vision is better with the distance correction, while at 51 cm vision is better with the near correction. At 76 cm neither lens offers normal vision. Uncorrected intermediate visual acuity generally declines with the loss of accommodative power and increasing refractive error. Individuals with myopia of less than 2.0 diopters (D) generally have better intermediate visual acuity without correction than with either a near or a distance correction. Younger subjects generally have better acuity under all conditions except subjects with uncorrected myopia exceeding 2.0 D.

The factors that act to influence intermediate visual performance and recommendations for further research are discussed.

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INTERMEDIATE VISUAL ACUITY OF PRESBYOPIC INDIVIDUALS WITH AND WITHOUT DISTANCE AND BIFOCAL LENS CORRECTIONS

I. Introduction.

Operators of aircraft and other high-speed vehicles of transportation must have optimum visual acuity to function safely and efficiently. Many of the visual requirements imposed on vehicle operators are inherent in the design and layout of the vehicle operator's work station; i.e., cockpit, cab, driver's seat. Where normal control-display relationships exist, many visual requirements are generated within a distance roughly described as arm's length or intermediate range. Several primary and component visual factors that influence visual performance at the intermediate range are listed in Table 1.

The distribution for ocular refractive errors peaks near emmetropia (no refractive error) and falls rapidly to each side with increasing hyperopia (farsightedness) and myopia (nearsightedness) (1). Refractive errors often shift from hyperopia toward myopia during the adolescent years (2) but generally remain unchanged during adulthood, though shifts in either direction may occur in later life (3). Astigmatism, with or without hyperopia or myopia, is usually caused by a warping of the corneal surface. Ocular astigmatism affects the pattern of light rays entering the eye and frequently requires correction by a toric-shaped spectacle lens for undistorted vision.

During childhood the crystalline lens within the eye can exert approximately 15 diopters (D) of accommodative power, which will allow a clear focus on objects approximately 7.0 cm (3.0 in) from the eyes. Thereafter, accommodation decreases progressively with age until almost all the focusing power is lost by the age of 60 years (4, 5). Between the ages of 40 and 50 years many individuals require reading glasses for close work or bifocal lenses where correction is also required for distance vision. Reading glasses or bifocal lenses are frequently prescribed to provide maximum clarity at 40 cm (16 in) and an effective clear vision range extending from approximately 30 to 50 cm. As accommodative power decreases further with age, trifocal lenses may be required for additional correction at the intermediate range.

The purpose of this study is to evaluate the interaction between various combinations of ocular refractive errors and accommodative powers as they affect visual acuity at viewing distances of 51, 76, and 102 cm (20, 30, and 40 in). Visual acuity determinations were made both with

TABLE 1.

Factors Influencing Readability at the Intermediate Range

Primary Factors	Component Factors
Visual	Refractive Error Accommodation Adaptation Oculomotor
Psychosensory	Interpretative Skills Emotional Status Reaction Time Experience Training
Biomedical	General Health Ocular Health Fatigue Drugs
Display	Digit Size Contrast Ratios Lighting View Distance Parallax
Environmental	Glare Hypoxia Vibration Toxic Products

optimum spectacle lenses for distance vision and near vision and without lens correction.

II. Methods.

Test subjects consisted of 249 volunteers from the FAA Aeronautical Center in Oklahoma City, of whom 194 (78 percent) were men and 55 (22 percent) were women. The mean age of the subjects was 48 years with a range of 35 to 69 years. Approximately 4 percent of the 498 eyes were screened but not evaluated because they had ocular astigmatism greater than 1.00 D or their visual acuity could not be corrected to 20/20 because of amblyopia, previous eye injury, or ocular disease.

Prior to data collection, a visual examination was made on each subject to determine his or her ocular history, visual acuity, ocular health, accommodative power, and optimum spectacle lens correction for distance (6 m, 20 ft) and for near (40 cm, 16 in) vision. On the basis of the results of the examination, each acceptable eye was categorized with respect to one of 27 subcategories of refractive error and accommodative power. Accommodation was measured monocularly under bright illumination by calculating the amount of concave lens that blurred or convex lens that cleared a row of equivalent 20/20 letters at 40 cm combined with a base value of +2.50 D.

The optimum lens to correct the subject's refractive error was determined objectively and subjectively without cycloplegic drops. The bifocal lens correction for near vision at 40 cm was determined under a luminance of 50 fL by adding convex spherical lenses in +0.25-D increments to the distance prescription until the subject reported no further acuity improvement in a row of 20/20 letters suspended 40 cm from the subject's eyes. Younger subjects frequently required no additional convex lens power to see clearly at 40 cm.

Test targets consisted of numerals graded in size to measure visual acuity over a range from 20/80 to 20/15. Numeral size was adjusted to measure visual acuity over the range noted above at each test distance (51, 76, and 102 cm). The numerals were white on a black background with a contrast ratio of 94 percent as measured with a Pritchard Spectra photometer, model 1970-PR. Photographs containing the numerals were attached to the display drum in horizontal rows with five digits of equal size in each row. All digits including zero were used in the display but no digit occurred more than once in the same row. A rotatable display drum assembly was used to present individual rows of digits through the central aperture in the occluder plate. Each subject viewed the digits while wearing a trial frame with the appropriate prescription lenses or with plano lenses (0.0 D) when a prescription was not required. Subjects having astigmatism of 1.0 D or less were corrected with an appropriate cylindrical lens during testing.

The test numerals were illuminated by a moderately bright white light adjusted in voltage so that 50 fL were reflected from a white oxide

diffuser plaque located adjacent to the viewing aperture in the occluder plate. The digits were presented monocularly, starting with the largest (20/80) and proceeding to the smallest (20/15), for each of the nine viewing conditions.

As the subject read the numerals, an operator scored errors by marking the digits read incorrectly on the subject's data sheet. Scoring was based on the last line that was read with not more than two errors. For example, if the subject incorrectly read three, four, or five of the digits in the 20/40 row and made no more than two errors in the 20/50 row (next largest digits), the score was 20/50. If a subject missed three or more digits on the 20/80 line, the score was arbitrarily assigned a value of 20/100. All test distances and viewing conditions were counterbalanced to minimize fatigue and/or learning effects.

III. Results.

Table 2 provides data relevant to each of the 27 subcategories of refractive error and accommodative power. Listed from top to bottom in each block is the following information: subcategory designation, number of eyes evaluated, mean age of the subjects, and range of ages. The marked variation in sample size between subcategories occurred because sufficient numbers of subjects with higher refractive errors did not volunteer for the evaluation. Mean performance scores for 16 or 27 subcategories are based on less than the desired sample size of 20 eyes; excessive numbers of subjects are included in several other subcategories. There were no volunteer subjects for subcategory H-IV, A-III.

The mean ages for subjects with accommodative power in ranges A-I, A-II, and A-III are 54, 47, and 41 years respectively. Figure 1 shows the effect of age on accommodative power for all test subjects.

Data presented in Figure 2 show the effect of viewing distance (51, 76, and 102 cm) on visual acuity for all subjects with hyperopic refractive errors. Mean visual acuity scores are shown for subjects under the following viewing conditions: with optimum lens correction for distance vision (solid line), with optimum lens correction for near vision (dashed line), and without lens correction (dotted line).

When hyperopic subjects with the lowest accommodative power (A-I) were evaluated with their optimum lens corrections for distance vision, mean acuity scores decreased from 20/30 or better at 102 cm to less than 20/50 at 51 cm. Visual performance under these conditions was generally consistent for all levels of hyperopia (H-I to H-IV). The same hyperopic subjects corrected optimally for near vision (40 cm) had visual acuity of 20/25 or better at 51 cm decreasing to 20/50 to 20/60 range at 102 cm. Again, performance scores were similar for all hyperopic subjects with low accommodative power. Data for these subjects indicate that at 76 cm, acuity better than 20/40 cannot be achieved with the spectacle lens for correction of either distance or near vision. With one exception, data indicate that visual acuity is consistently better at the intermediate

TABLE 2. Descriptive Data Relevant to Each Subcategory of Refractive Error and Accommodative Power

Accommodation Level	MYOPIA					HYPEROPIA			
	4.25 → UP	3.25 - 4.00	2.25 - 3.00	1.25 - 2.00	>0.0 - 1.00	>0.0 - 1.00	1.25 - 2.00	2.25 - 3.00	3.25 → UP
0.25 to 1.00	M-V, A-I N=13 51.8 47-57	M-IV, A-I N=4 53.5 50-60	M-III, A-I N=10 54.2 50-60	M-II, A-I N=22 54.5 49-69	M-I, A-I N=28 52.1 46-61	H-I, A-I N=66 55.1 47-68	H-II, A-I N=43 55.4 47-64	H-III, A-I N=20 56.5 47-67	H-IV, A-I N=11 52.4 41-64
1.25 to 2.00	M-V, A-II N=3 48.3 48-49	M-IV, A-II N=2 46.0 43-49	M-III, A-II N=5 45.0 41-48	M-II, A-II N=5 48.6 44-54	M-I, A-II N=28 46.3 41-56	H-I, A-II N=29 47.3 42-59	H-II, A-II N=10 46.8 42-53	H-III, A-II N=2 47.0 41-53	H-IV, A-II N=2 46.0 46-46
2.25 to 5.00	M-V, A-III N=11 41.7 36-48	M-IV, A-III N=8 40.6 36-44	M-III, A-III N=16 40.9 37-44	M-II, A-III N=28 41.0 37-46	M-I, A-III N=58 41.2 35-45	H-I, A-III N=50 41.4 35-47	H-II, A-III N=6 41.3 40-42	H-III, A-III N=1 38.0 38-38	H-IV, A-III N=0 --- ---

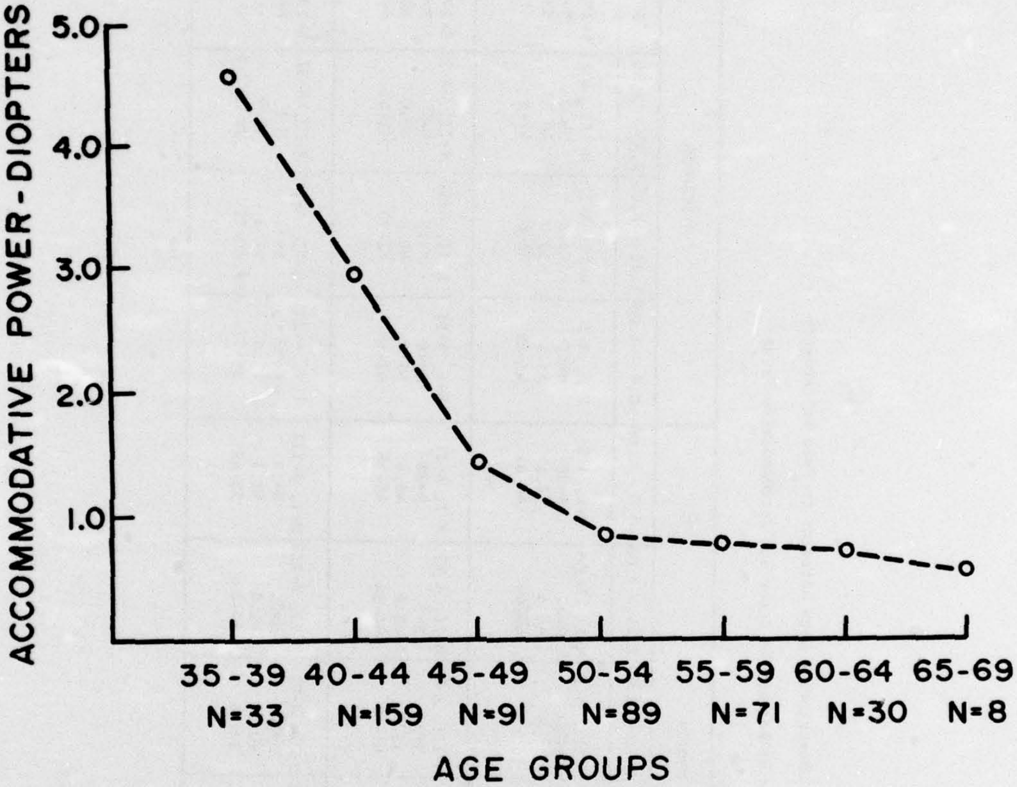

Figure 1. Accommodative power was measured by the amount of concave lens that blurred or convex lens that cleared a row of letters at 40 cm combined with a base value of +2.50 D.

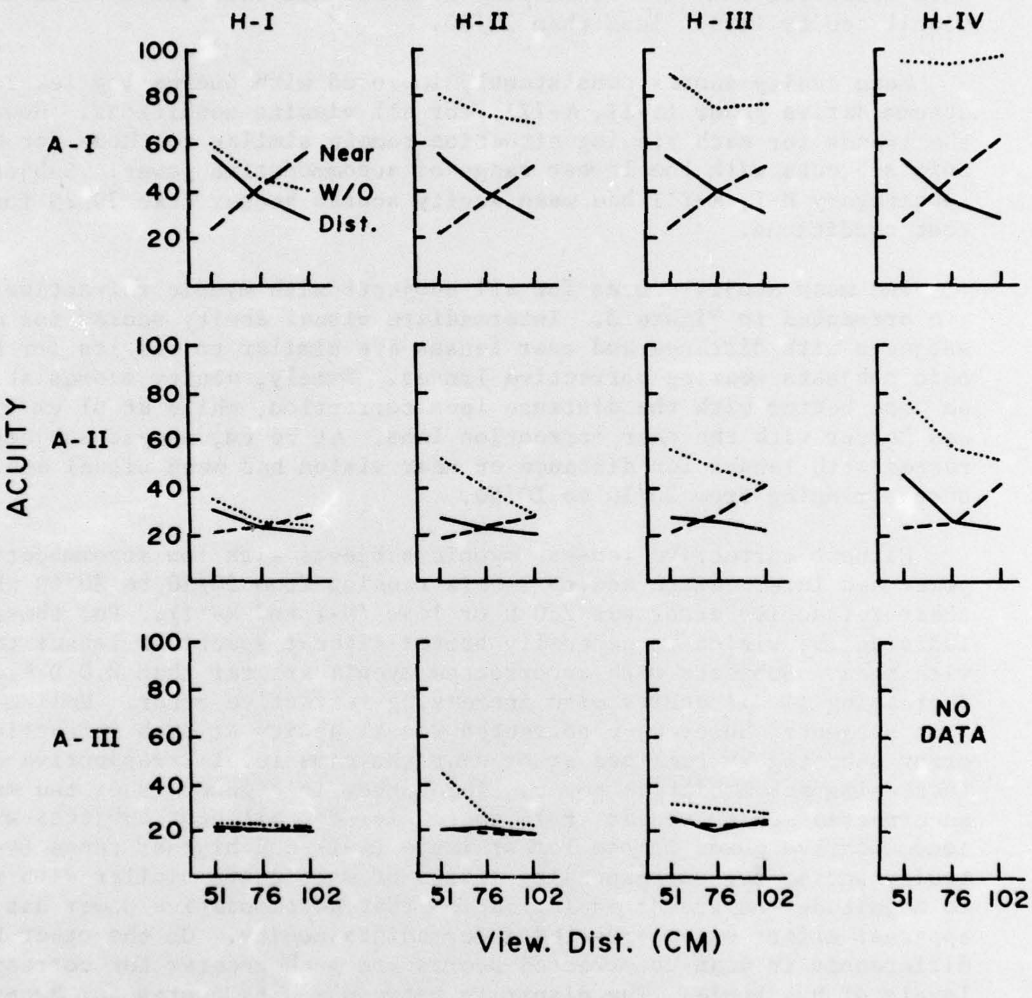

Figure 2. Mean visual acuity scores at 51, 76, and 102 cm for hyperopic subjects viewing test numerals without lenses (dotted line), with lenses for distant vision (solid line), and with bifocal lens (dashed line).

range with either the near or distance correction than without lenses. The exception occurred in subcategory H-I, A-I, at the 102-cm viewing distance. Figure 2 also shows that uncorrected intermediate visual acuity declined progressively with increasing levels of hyperopic refractive error. Also, performance scores for subcategory H-IV, A-I would have decreased somewhat if display numerals had been included to measure visual acuity levels less than 20/80.

Mean acuity scores consistently improved with increasing levels of accommodative power (A-II, A-III) for all viewing conditions. However, the trends for each viewing situation remain similar to those for hyperopic subjects with the lowest range of accommodative power. Subjects in subcategory H-I, A-III had mean acuity scores better than 20/25 for all test conditions.

The mean acuity scores for all subjects with myopic refractive errors are presented in Figure 3. Intermediate visual acuity scores for myopic subjects with distance and near lenses are similar to results for hyperopic subjects wearing corrective lenses. Namely, acuity scores at 102 cm were better with the distance lens correction, while at 51 cm vision was better with the near correction lens. At 76 cm, myopic subjects corrected with lenses for distance or near vision had mean visual acuity scores ranging from 20/30 to 20/50.

Without corrective lenses, myopic subjects with low accommodative power had intermediate acuity levels ranging from 20/20 to 20/40 when their refractive error was 2.0 D or less (M-I and M-II). For these individuals, vision is generally better without spectacle lenses than with them. Subjects with uncorrected myopia greater than 2.0 D had decreasing visual acuity with increasing refractive error. Unlike hyperopic subjects, however, uncorrected visual acuity at each refractive error subcategory remained at or near the same level irrespective of increasing accommodative power. The curves in Figure 4 show the mean uncorrected acuity scores at 76 cm (30 in) for all test subjects with accommodative power in the lowest range (A-I) and highest range (A-III). Acuity scores for corresponding levels of myopia are similar with respect to magnitude and trend, an indication that accommodative power has no apparent effect on uncorrected intermediate acuity. On the other hand, differences in mean uncorrected scores are much greater for corresponding levels of hyperopia. The disparity between acuity scores for hyperopic eyes can be explained in terms of the location of the so-called far and near points of the eye as a function of refractive error and viewing distance. Davson (6) provides a comprehensive discussion of several principles of physiological optics concerned with visual acuity, refractive error, and accommodative power.

IV. Discussion.

Vehicle operators, pilots, and air traffic control specialists are often required to view instruments and manipulate control mechanisms located in the intermediate vision range. They are also required to

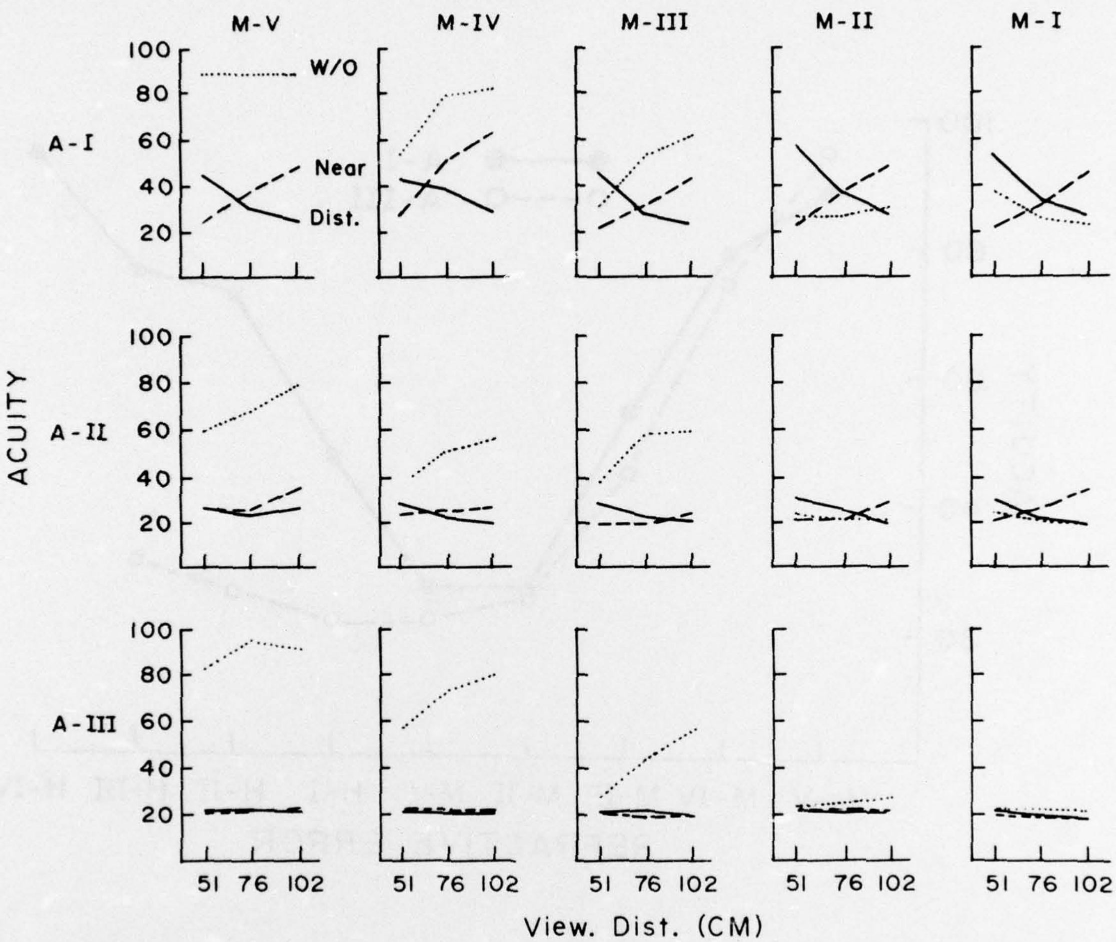

Figure 3. Mean visual acuity scores at 51, 76, and 102 cm for myopic subjects viewing test numerals without lenses (dotted line), with lenses for distant vision (solid line), and with bifocal lens (dashed line).

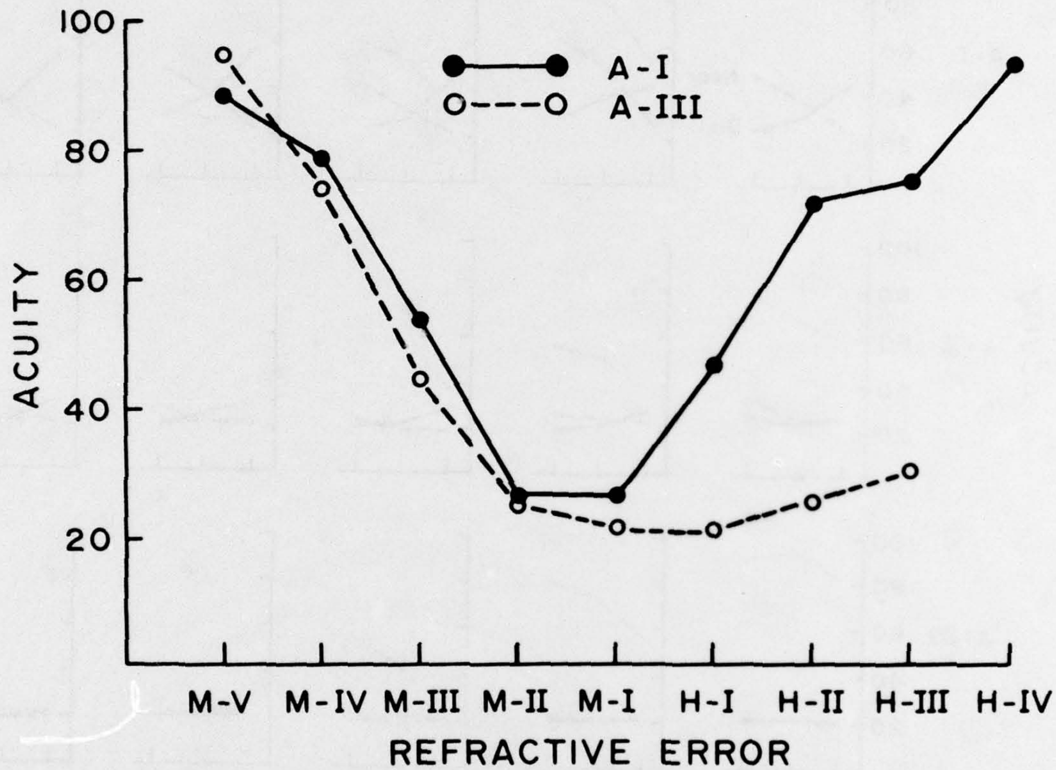

Figure 4. Mean intermediate visual acuity scores at 76 cm without corrective lenses for subjects with lowest (0.25 to 1.00 D.) and highest (2.25 to 5.00 D.) level of accommodative power.

monitor displays located above or to either side of the operator's central visual field. Illumination and viewing distance may also vary considerably between work stations. Consideration must therefore be given to the adaptability and limitations of the human visual system, particularly when older individuals are involved.

Data indicate not only decreasing accommodative power with advancing age, but also decrements in several other performance attributes common to presbyopic individuals. McFarland et al. (7) found that visual sensitivity to a stimulus light decreased progressively for each decade of age for subjects ranging in age from 16 to 89 years. Guth's data (8) indicate that individuals in their sixties required twice as much light as 20-year-olds to read printed words. A study by Mourant and Langolf (9) indicated that elderly individuals required 10 times more light than did young people to obtain 95-percent-correctness scores for a symbol readability task. Other investigators (10, 11) have shown that visual acuity of elderly individuals may decline because of retinal changes or clouding of the ocular media. Melton and Wicks (12) have shown that accomplishing binocular fusion to overcome double vision is slower for older men (45 to 60 years) than for younger men (25 to 30 years). Further degradation in visual performance has been reported to occur under conditions of hypoxia (13, 14), hypoglycemia (15), small doses of carbon monoxide (16), therapeutic doses of common drugs (17), and alcohol (18).

Trifocal lenses, generally considered the most effective measure to improve intermediate visual acuity, are not worn by many older pilots. Harper and Kidera (19) cited natural human reluctance to wearing multifocal lenses and unawareness of reduced intermediate vision as contributing factors. Their investigation revealed that more than 90 percent of the senior pilots with minimal accommodation had less than 20/20 vision at 76 cm (30 in) under bright ambient illumination. Furthermore, they stated that a lens correction for near vision (35 to 40 cm) could not be used effectively for reading aircraft instruments because of narrowed depth of focus through bifocal lenses. Data from a recent survey (20) indicate that only 14 percent of the private pilots with accommodative power less than 2.0 D wear trifocal lenses.

It is incumbent on vision specialists to obtain sufficient information about their patients' jobs that appropriate ophthalmic lenses can be prescribed. Often an individual will require several pairs of glasses or occupational multifocal lenses to perform effectively all phases of an operational task. Also, recipients of new eyewear must be given instructions concerning the capabilities and limitations of their spectacles or contact lenses. Backman and Smith (21) investigated the acceptance of several occupational multifocal lenses designed for pilots and engineers flying commercial aircraft. Their report includes data concerning flight deck specifications of 10 commercial aircraft and recommends design characteristics for spectacle lenses used by flight crews with incipient and advanced presbyopia.

Finally, manufacturers and designers of charts and instruments should, when necessary, consult specialists in human factors to match performance characteristics of vehicle operators to future chart displays and cockpit designs. Static medical defects that degrade operator performance and safety must also be considered. Dille and Booze (22) have examined the effects of selected physical defects on accident rates of civilian airmen and discussed several factors that are necessary if reliable information concerning accident reporting is to be obtained.

V. Summary and Recommendations.

The results indicate that without spectacle lenses, intermediate visual acuity is variable, depending on the individual's ocular refractive error, accommodative power, and the viewing distance. Also, data indicate that for individuals with accommodative power less than 2.0 D visual acuity at the intermediate range is generally weaker without lenses than with spectacle lenses for distance or near vision. However, individuals with myopia of less than 2.0 D generally have better intermediate vision without rather than with bifocal or distance vision corrective lenses. Data indicate that individuals with higher levels of accommodative power have less difficulty throughout the intermediate range of vision.

When viewing the test numerals through the optimum lens for near vision (40 cm, 16 in) hyperopic and myopic subjects with low accommodative power have relatively good acuity at 51 cm (20 in) and a progressive decline in acuity at 76 and 102 cm (30 and 40 in). Under the same test conditions, subjects with more accommodative power have improved acuity at the middle (76 cm) and distal (102 cm) portions of the intermediate range.

Conversely, individuals with low accommodative power have relatively good visual acuity at 102 cm when using a spectacle lens for distance vision, but their performance declines progressively at 76 and 51 cm. Also, visual acuity at the middle and proximal portions of the intermediate range (76 and 51 cm) improves with increasing levels of accommodative amplitude for all refractive error subcategories.

At the 76-cm viewing distance, neither the distance nor the near lens correction provides optimum visual acuity for individuals with low accommodative amplitude. Vision at 76 cm ranges from 20/30 to 20/50 for individuals with advanced presbyopia.

The data from this study and the data from the referenced sources point to the need for further research directed at intermediate vision of people operating aircraft and other vehicles. Several suggestions that merit further investigation are listed below.

1. A comprehensive description of intermediate vision tasks common to various segments of the transportaion environment should be compiled. Emphasis should be directed to the display characteristics, frequency of viewing, and ambient operational conditions.

2. Data should be obtained concerning minimum visual acuity levels necessary to read various instrument displays with respect to time, accuracy, age, and stress created.

3. The optimum size, location, and shape of the bifocal and trifocal segments of a multifocal lens used in performing specific visual tasks need further investigation. In addition, the effectiveness of continuous power (Varilux, Omnifocal, or Younger Seamless) multifocal lenses should be evaluated in the operational environment.

4. Consideration of medical standards for intermediate vision should be made with respect to operator classification, diagnostic techniques, and minimum performance levels.

5. Techniques should be developed to demonstrate the effectiveness and limitations of bifocal and multifocal lenses in the operational environment. Methods to ease the sometimes adverse psychophysiological impact of these lenses should be explored.

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